ALPS General Conference Call, February 11, 2003

Viewgraphs for PMI Testing Subgroup

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Liquid/Particle Interaction Experiments at the University of Illinois

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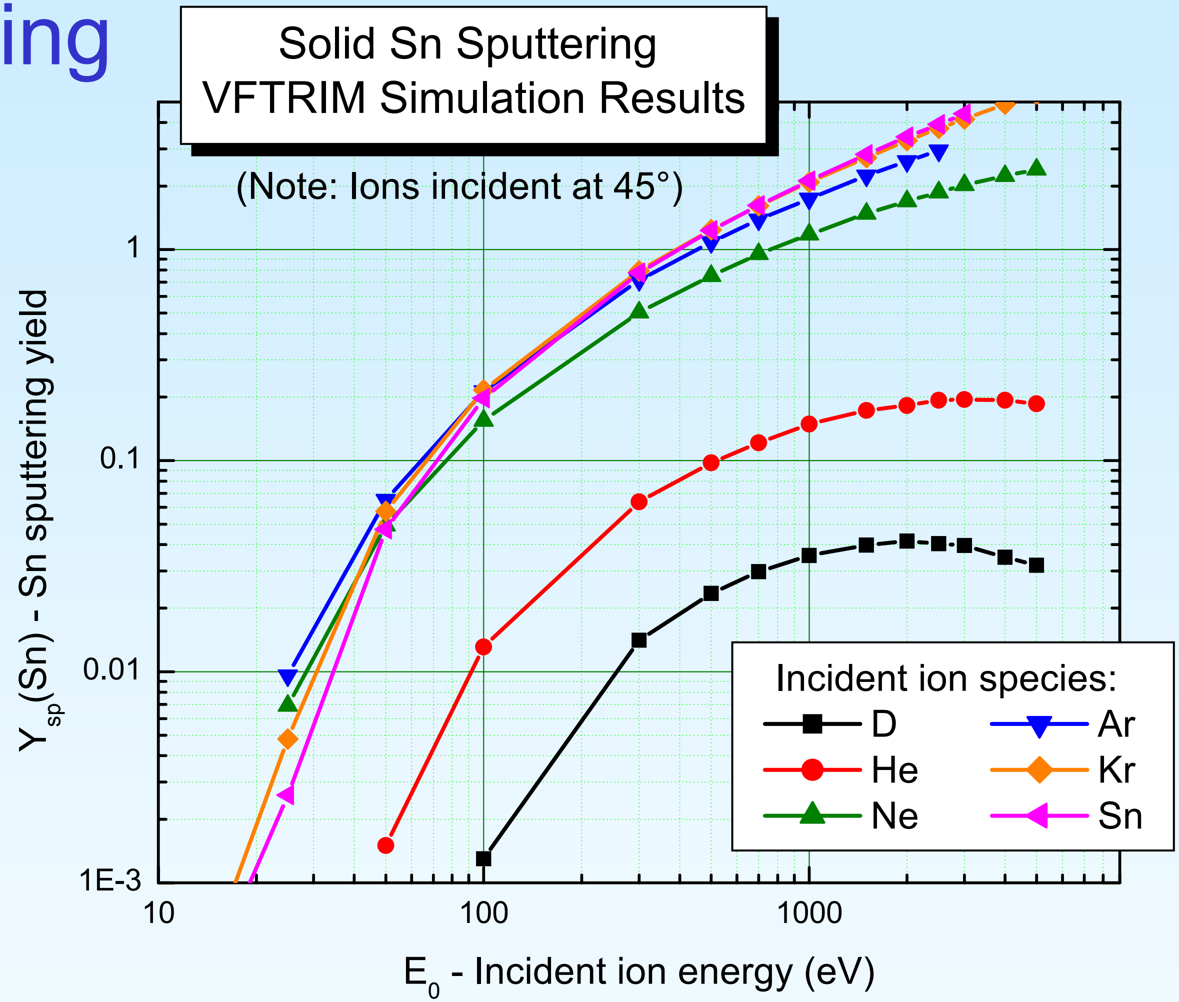
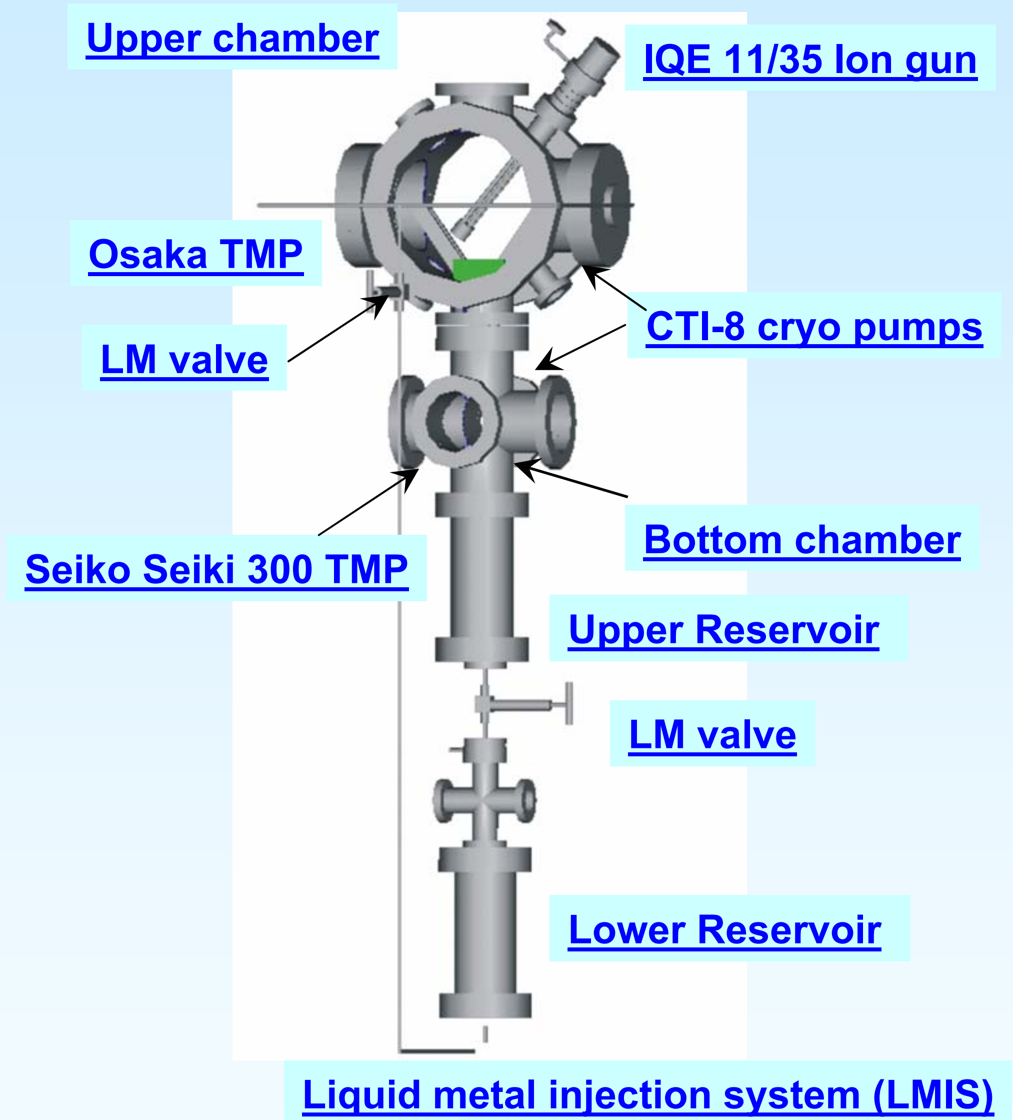
VFTRIM simulation of solid Sn sputtering

- Solid Sn with a rough surface (2.05 fractal dimension) has been simulated for various incident ion species.
- 100,000 flights per case
- Using sbe = 3.12 eV (from heat of sublimation)
- Self-sputtering yield for solid Sn exceeds unity at ion energies around 400 eV.

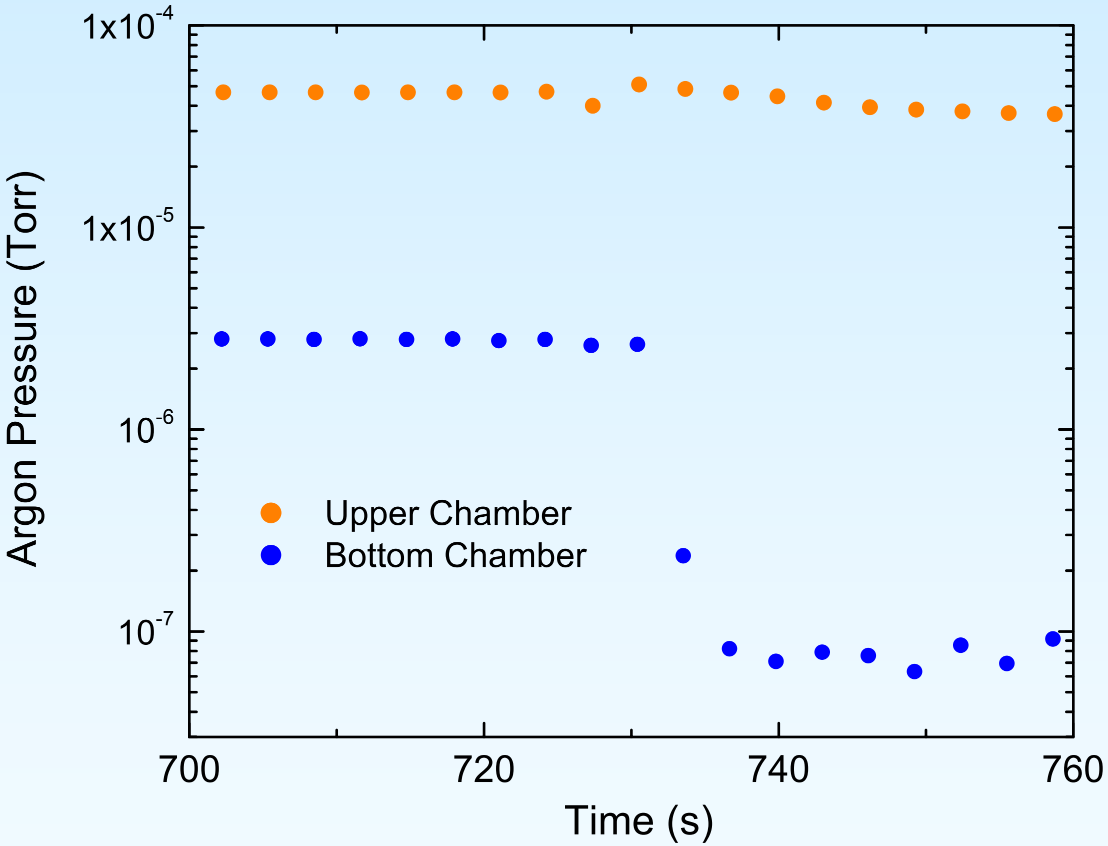


General FLIRE Experimental Design

- The vacuum system is composed of 2 TMPs and 2 cryo pumps.
- SPECS IQE 11/35 Ion gun source provides at least 10^{14} ions/cm^2/sec.
- Upper and lower chamber are connected by 0.3 cm^2 orifice.
- Upper and lower reservoirs hold and transport liquid Li
- RGA-QMS system for both chambers
- LM compatible valves

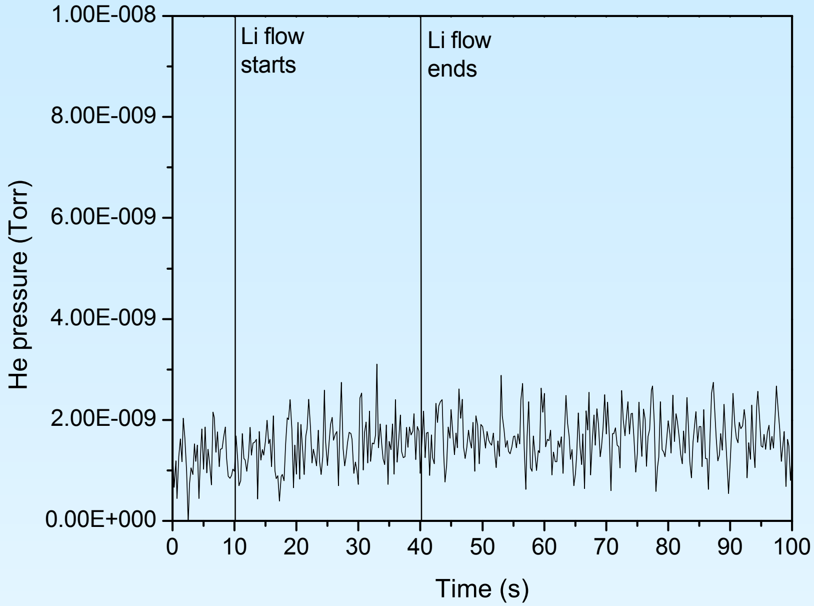


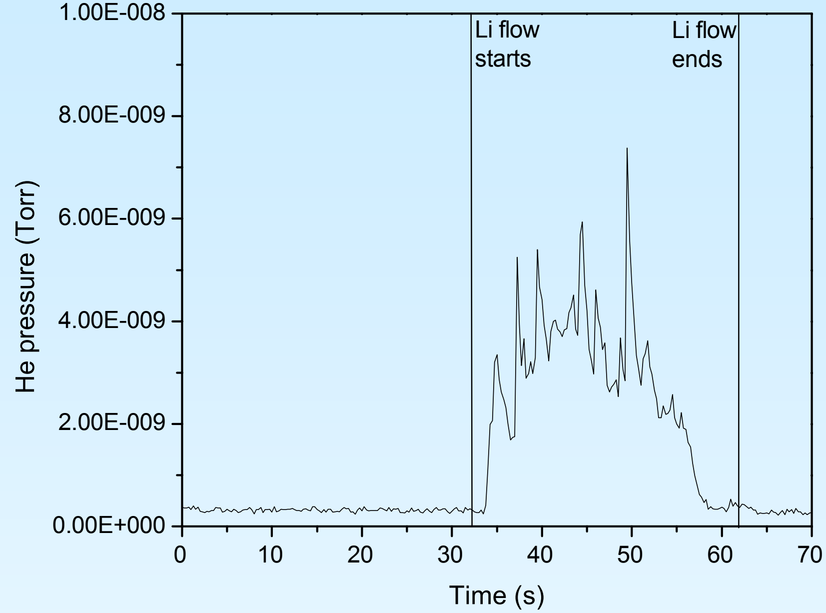
Chamber decoupling during Li flow



- Ar pressure in the upper chamber 0.1 mTorr
- At 730 seconds, the lithium flow was started
- Notice the drop of the Ar signal in the lower chamber!

He retention in flowing Li

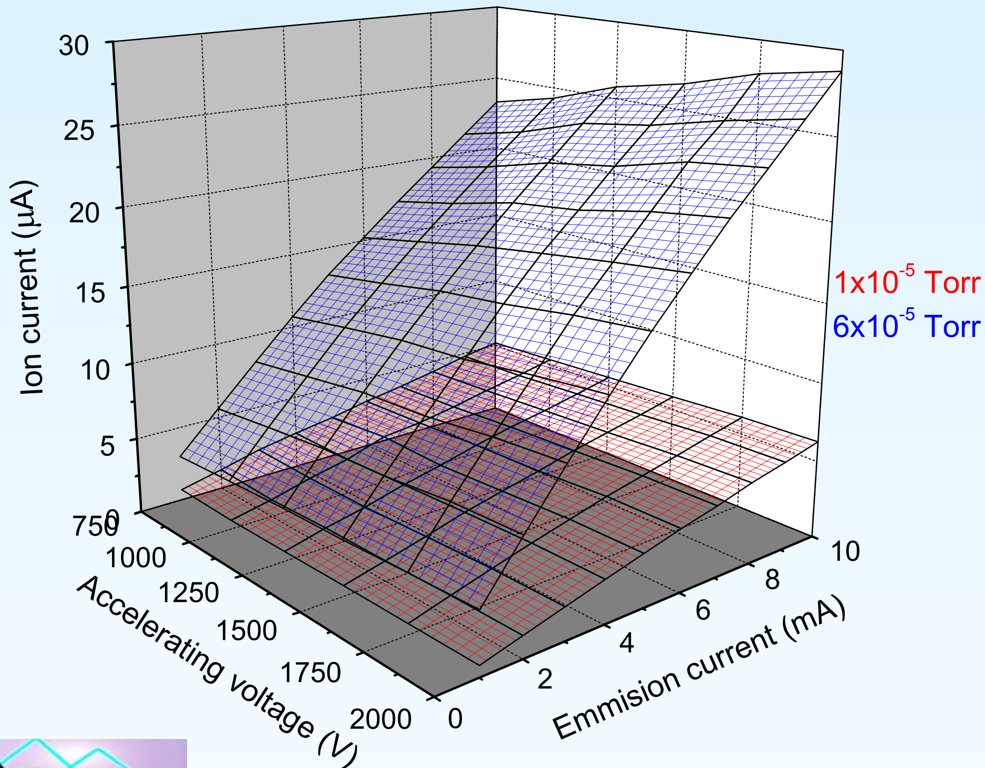




- He retention has been observed in FLIRE
- The graphs show He traces in the lower chamber during Li flow: on the left, a run with the beam turned on; on the right, a run with gun operating at 1 keV
- Pressure of ~ 2×10^{-5} Torr on top chamber in both cases
- Retention is on the order of 0.01 – 0.1% for FLIRE conditions
- Diffusion coefficient estimated to be on the order of 10^{-4} cm^2/s (based on initial estimates)

Current activities in FLIRE

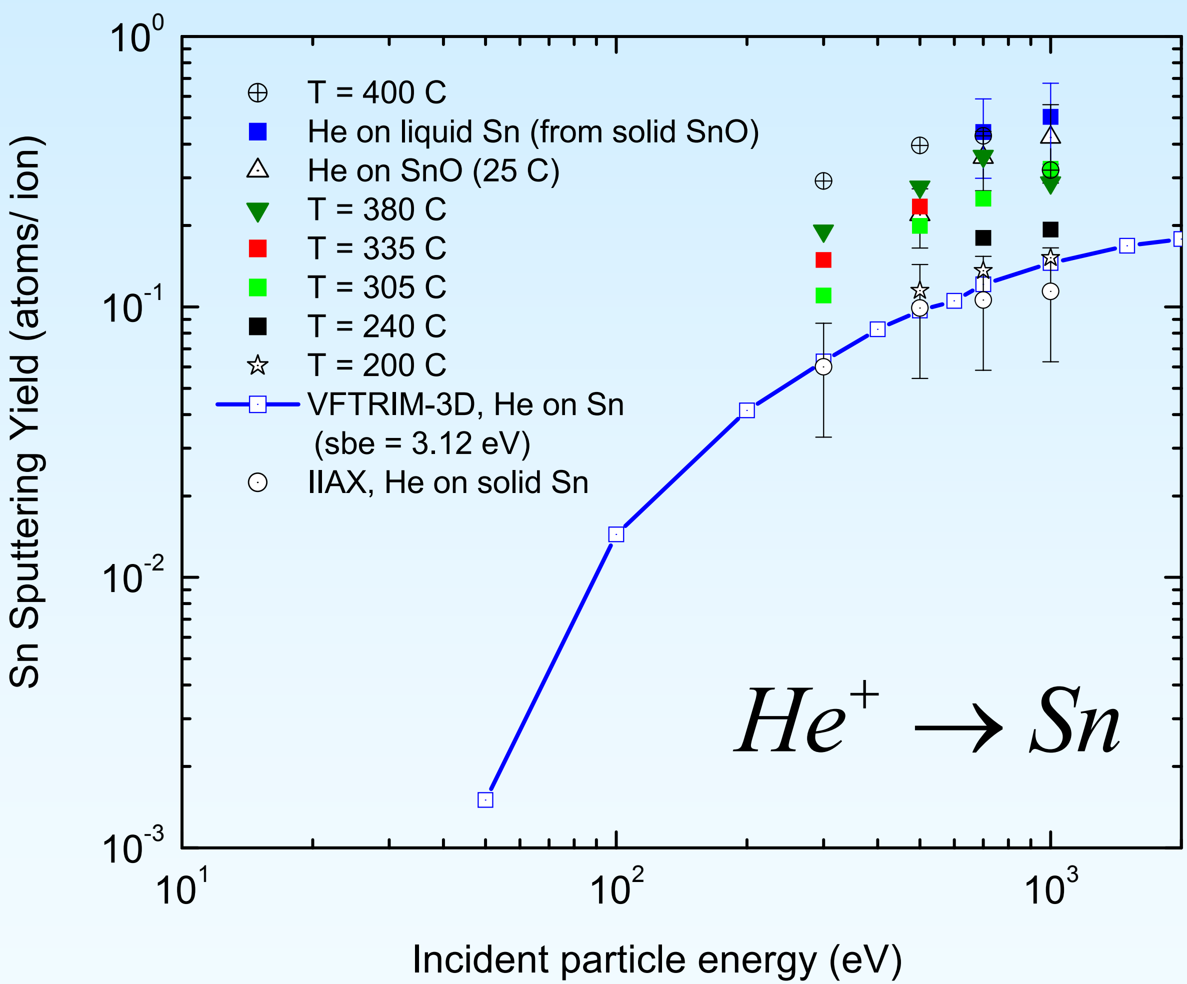
- Ion gun cleaning and total ion current measurements (see graph)
- Tests and measurements with FLIRE ramp replica underway (see photograph)
- TDS chamber installed and diagnostics tested
- Planning for RGA upgrade to magnetic sector (better sensitivity to low mass species)



Upcoming activities in FLIRE

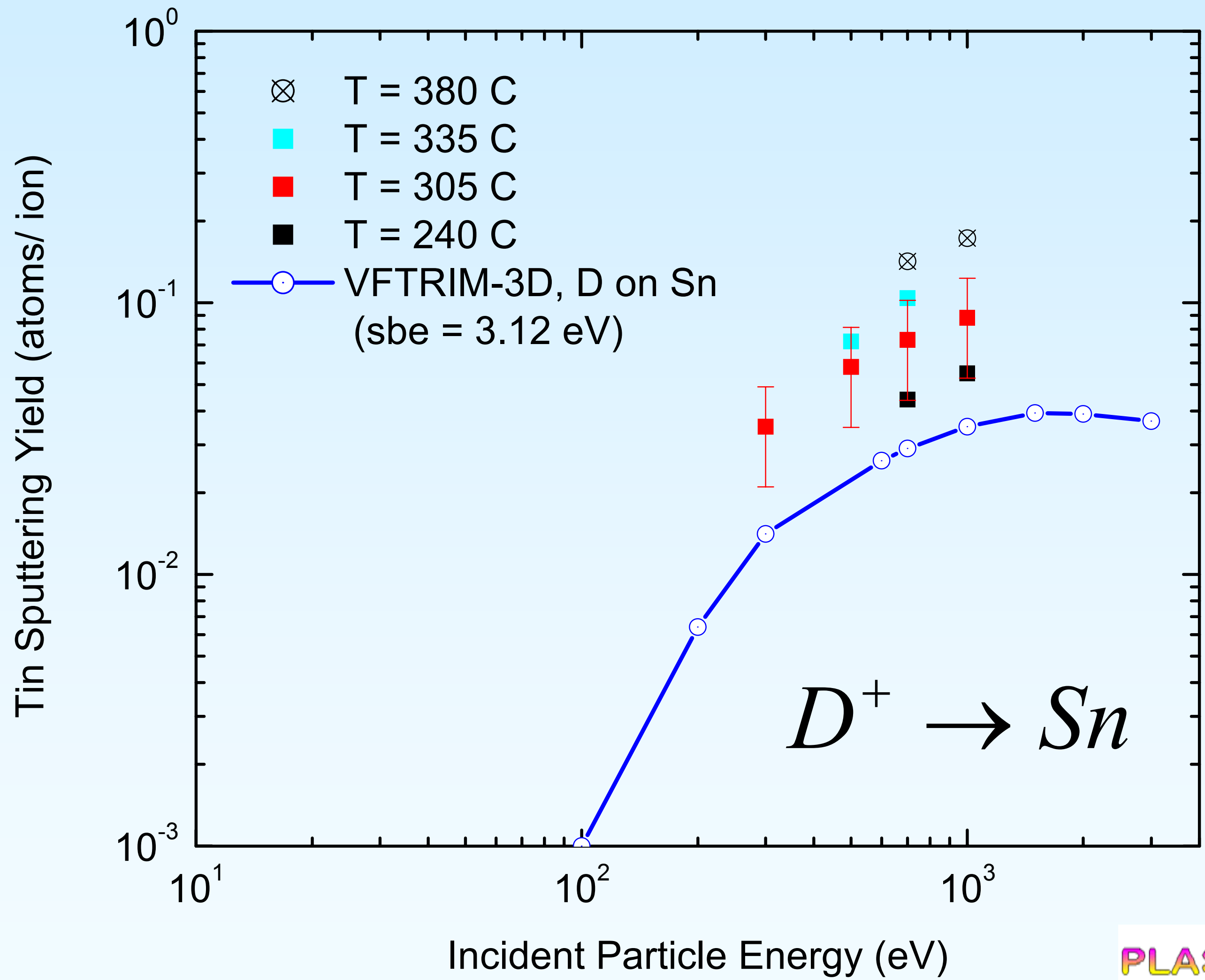
- Single stream experiments (folding effects? compromised seal? differences with two-stream results?)
- Discard long-term He retention by using the TDS chamber (increase T ~ 600 °C)
- Higher fluence experiments with DC plasma source (bubble formation?)
- Continue and complete Hydrogen experiments (retention and release measurements), both low (ion beam) and high (DC plasma) fluence
- Modeling effort will continue (HEIGHTS, MAID)
- Installation of additional diagnostics (IR imaging, ultrasonic thickness measurements)
- Preparation for switch to Ga as working fluid

Sn sputtering vs incident particle energy by He$^+$ bombardment in IIAX



- Temperature dependence of tin sputtering found at various incident particle energies
- Unlike Li, temperature dependence is not as strong
- For both He and D, yields are slightly greater than the *neutral* sputtering yield for liquid lithium at similar temperatures (note: Sn is believed to sputter in the neutral state whereas in Li ~2/3 of all sputtered particles are ionized)

Sn sputtering vs incident particle energy by D^+ bombardment



Summary/Future Plans in IIAX

Summary

- Sn sputtering yields have been obtained due to light ion bombardment at $300 < E_0 < 1000$ eV and $240 < T < 400$ °C.
- While tin's total sputtering yield is much less than that of lithium, once the high level of ionization of sputtered lithium particles is taken into account the sputtering of tin is marginally higher.
- Liquid tin does show temperature dependence although not as much as Li.
- Need to investigate mechanisms responsible for enhancement

Future Activity

- Bubble formation in liquid Li and Sn
- Ion-induced secondary ion emission in liquid Li and Sn (including any adsorbate effects in the case of Li)
- Heavy ion (Ne, Ar, Kr) sputtering of liquid Li and Sn
- Lithium segregation effects in liquid Sn-Li
- Long term: higher target temperature capabilities (upwards of 800°C)
- Continue development of temperature-dependent liquid models and Monte Carlo simulation codes

UCSD-PISCES ALPS/ALIST Progress Report

S.C. Luckhardt, M. Baldwin, L. Cai, R. Doerner, E. Hollmann, S. Indrakanti, T. Lynch, R. Seraydarian, and the UCSD PISCES Group

Department of Mechanical and Aerospace Engineering

Center for Energy Research

UC San Diego

February 11, 2003

PISCES Group Research Tasks ALPS/ALIST 03

- Liquid lithium experiment in CDX-U.
- Preparation for DiMES lithium experiment.
- Deuterium retention and release experiments and modeling.
- Thermal/particle transport modeling.

PISCES ALPS-ALIST summary 12/02-2/03

Liquid lithium experiment in CDX-U.

1. R. Seraydarian to PPPL for 2 wks in February to assist in bringing CDX-U into ohmic operation.
2. Trouble shooting and shake down accomplished and initial plasmas of 25kA current were produced.
3. High speed imaging camera diagnostic being prepared.
4. CDX-U is now in operation with bare stainless steel limiter tray.
5. Seraydarian will participate in stainless limiter benchmarks experiment 2wks, and liquid lithium fill experiment starting in March.

Preparation for DiMES lithium experiment.

1. Liquid lithium sample preparation to be done at UCSD.
2. Tests of compatibility of liquid lithium with DiMES components, including BN3 insulator, being done at PISCES.

PISCES ALPS-ALIST summary 12/02-2/03 (cont.)

Deuterium/Helium retention and release experiments and modeling.

1. **Experiments with liquid gallium continuing on PISCES-E.**
2. **Further evidence for 100's ppm range deuterium retention in liquid gallium.**
3. **Retention appears to follow ~exp(-W/T) scaling.**
4. **Caution! These are preliminary results.**
5. **Continuing experiment will complete temperature scaling, investigate role of redeposited gallium in retention process.**

Thermal transport in flowing liquids modeling.

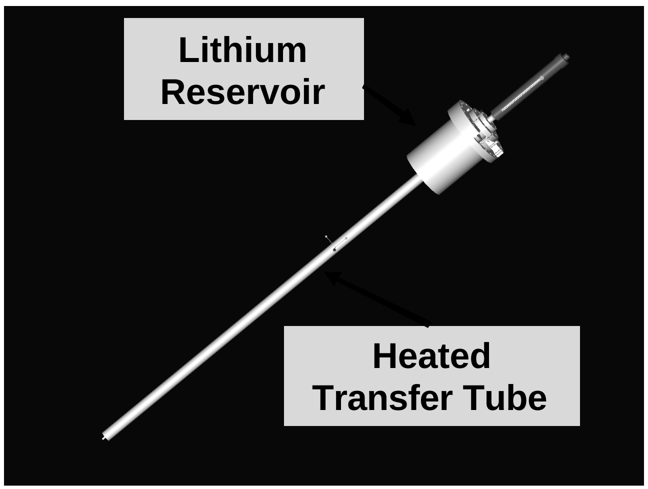
PFC2D model for thermal and diffusive particle transport in flowing liquid metals.

PFC2D calculates convection-diffusion heat transport under plasma flux loading conditions. Temperature response of surface and bulk liquid, surface evaporation, and non-linear temperature dependent thermal transport coefficients are included in model.

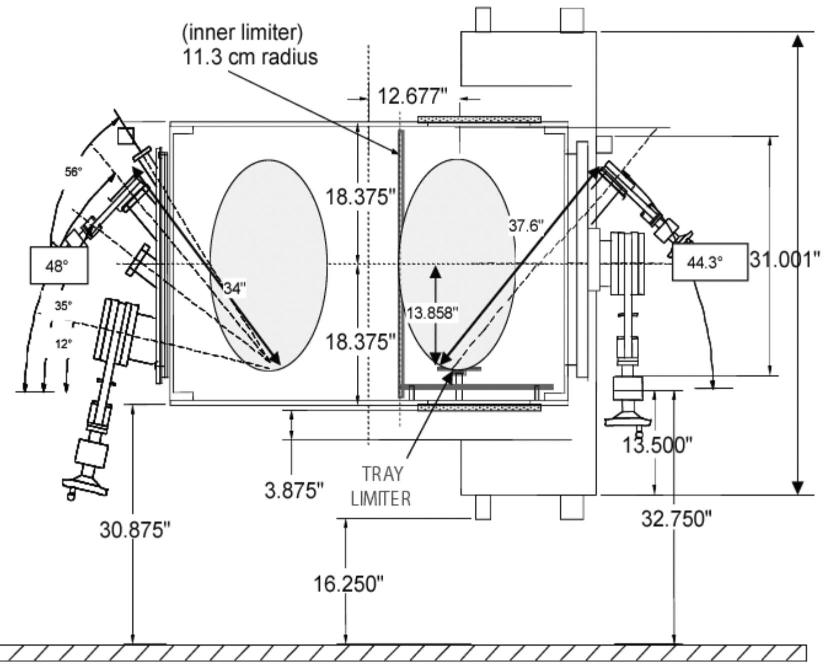
Modeling continuing in preparation for NSTX ALIST calculation.

UCSD liquid lithium delivery system for liquid lithium limiter experiment on CDX-U

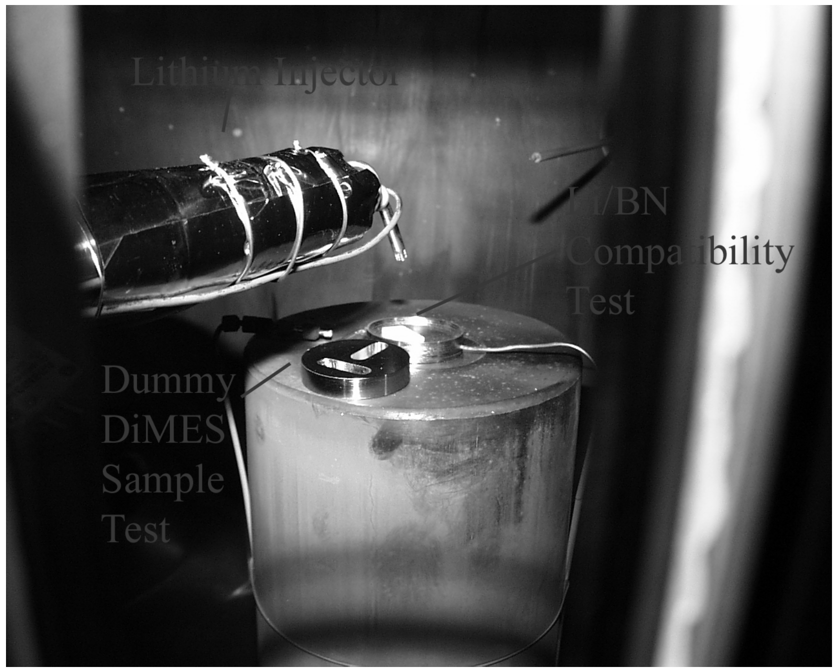
UCSD Liquid Lithium Phase-separator Injector



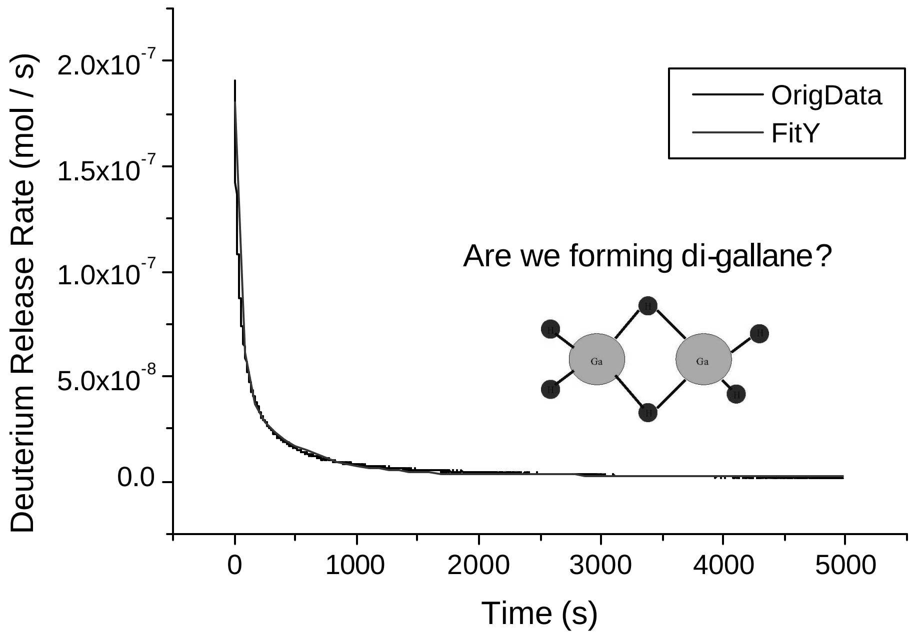
Elevation CDX-U



Li Tests for DiMES experiment PISCES-E



Apparent retention of deuterium in liquid gallium observed. Release of 500 appm of deuterium with time constant ~ 60sec. Further experiments needed to determine pumping effectiveness.

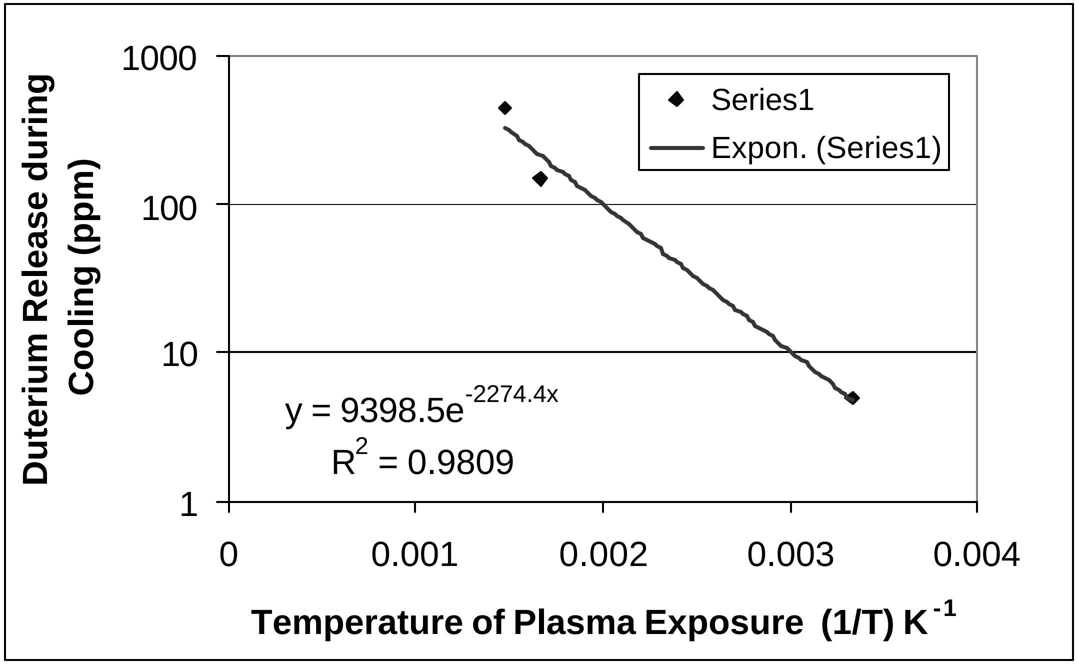


- Temp. = 400°C
- Duration 7200 s
- Retained D

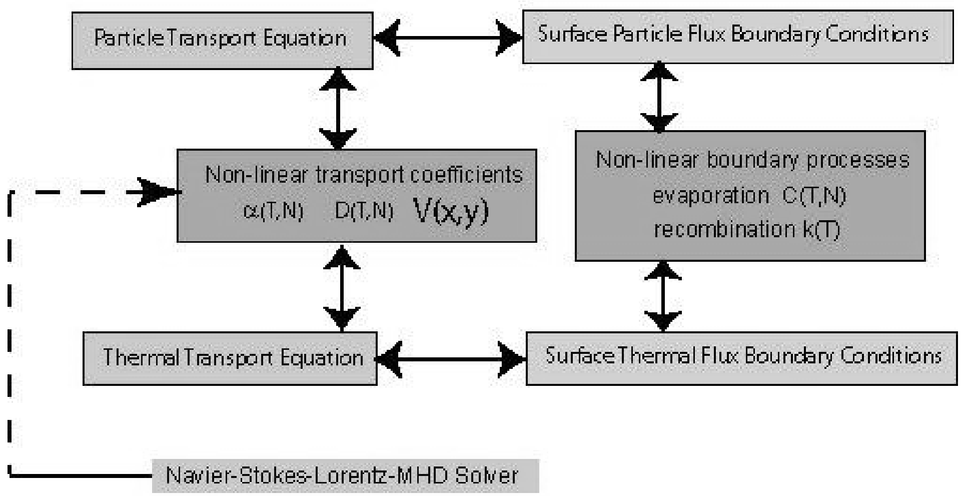
  4.01×10^{-05} moles

  2.4×10^{19} atoms
- Retention ~ 500 appm

Deuterium retention in liquid gallium follows exponential temperature dependence.
Experiments continuing to fill out temperature curve.



PFC2D Modeling Code:
Thermal and particle transport in flowing plasma facing layers



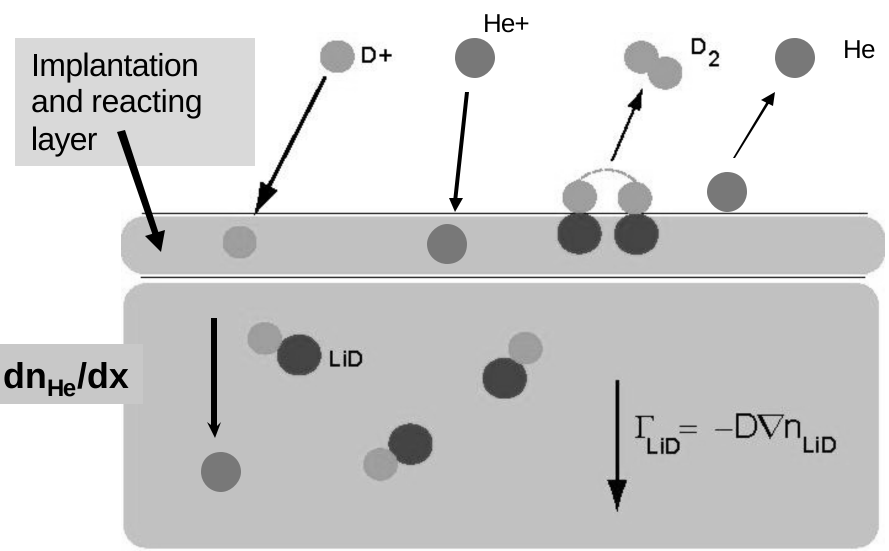
PFC2D capabilities and methods

- Finite element code
- Time dependent or time indepenent modes
- Neumann mixed bondary conditions, non-linear solver

PFC2D model for hydrogen and helium retention and release in liquid lithium (and gallium) metals:

- **Chemical reactions in the bulk and the surface**
- **Molecular and atomic species transport model**

Hydrogen/helium retention and release in liquid lithium



G_{He}**= -D** $\mathbf{dn_{He}/dx}$

D_2 and D Adsorption on Sn

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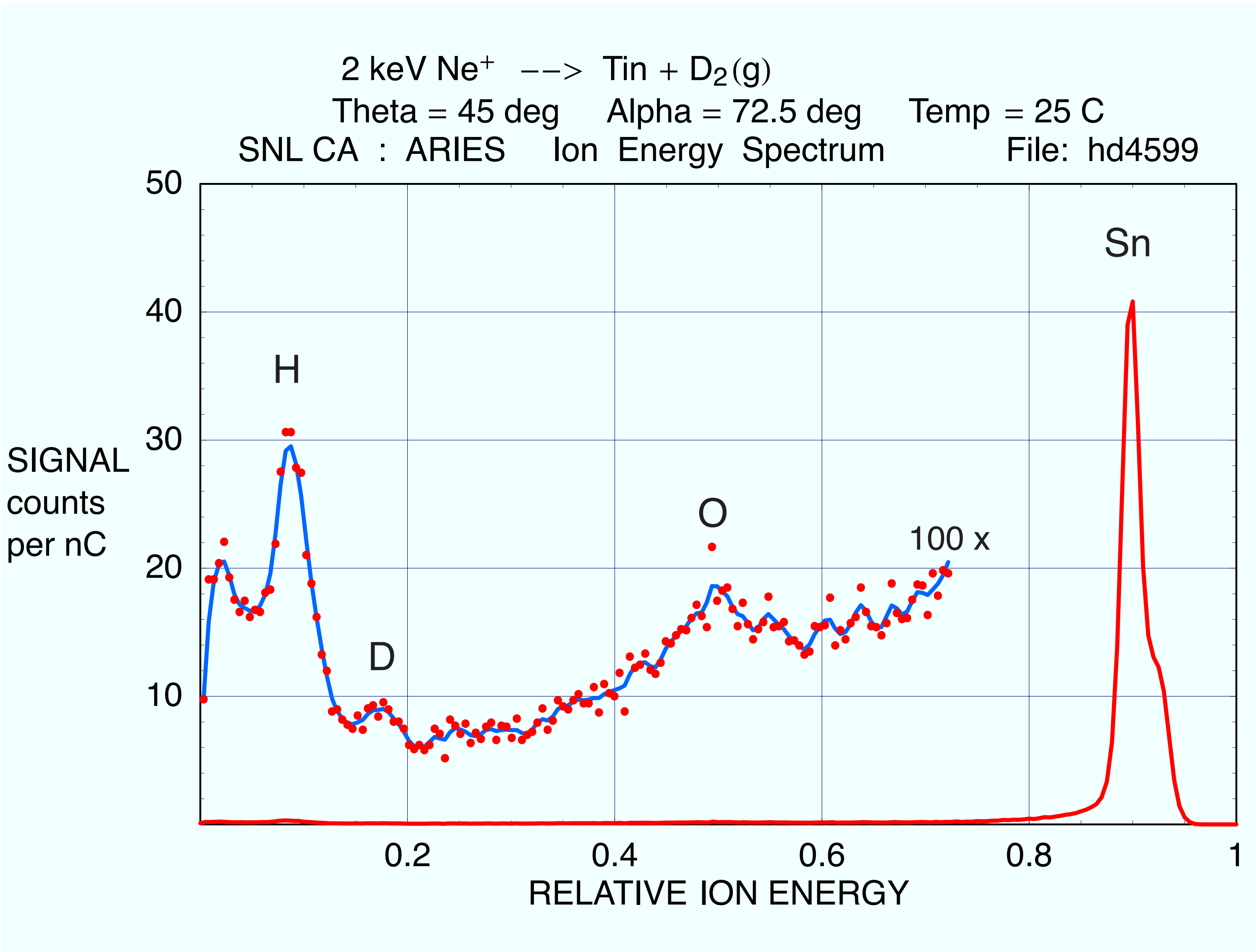
Livermore, CA 94551–0969

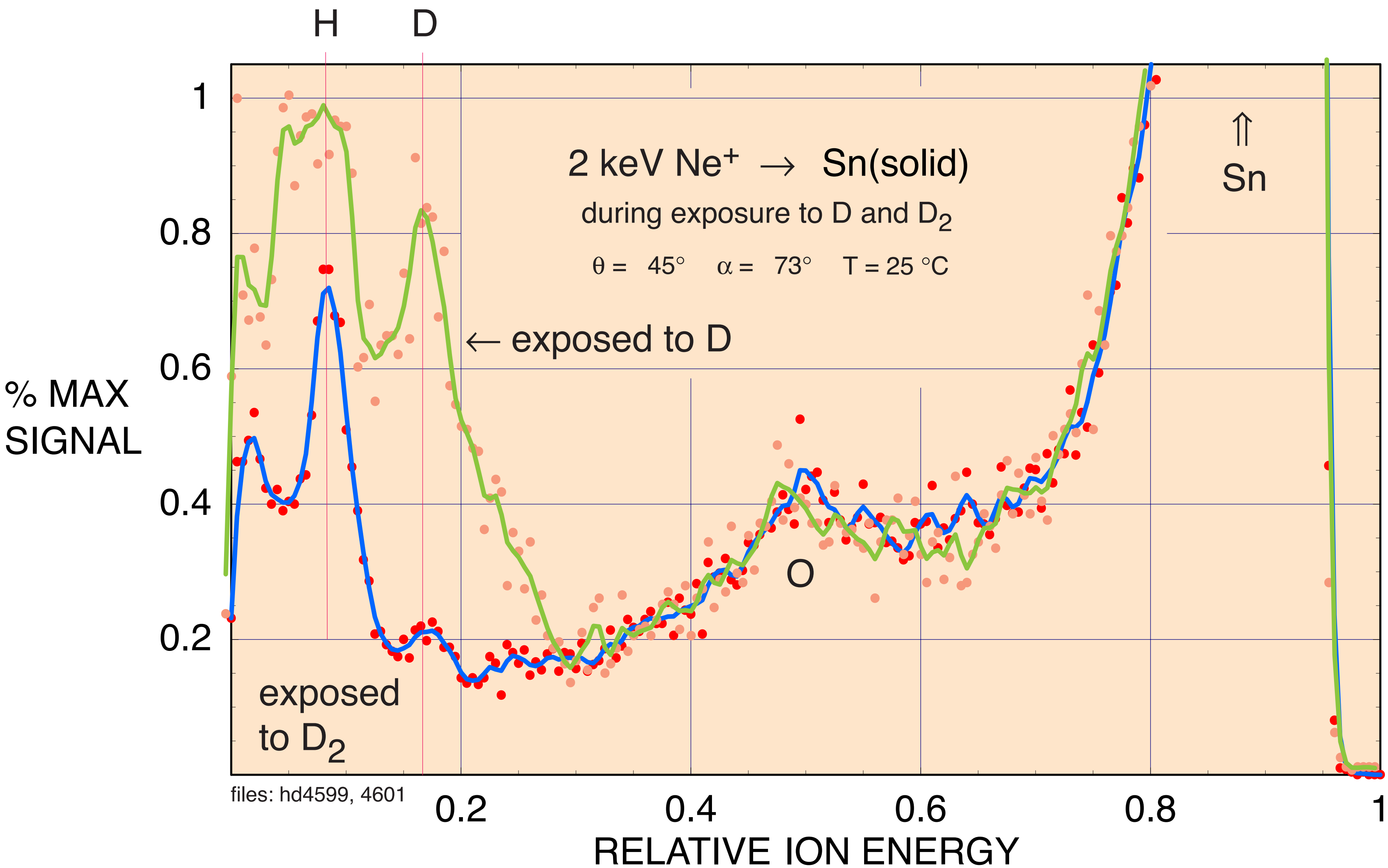
Synopsis

- To wrap-up our study of PMI effects on tin, we compared adsorption of molecular and atomic deuterium on tin surfaces.
- LEIS/DRS was used to monitor Sn surface composition during exposure to D_2 and D at various temperatures.
- We found that D_2 doesn't adsorb on either solid or liquid Sn. Atomic D does adsorb on solid Sn, but not on liquid Sn.
- In a fusion reactor, we expect liquid Sn to be a high recycling, low-inventory material.

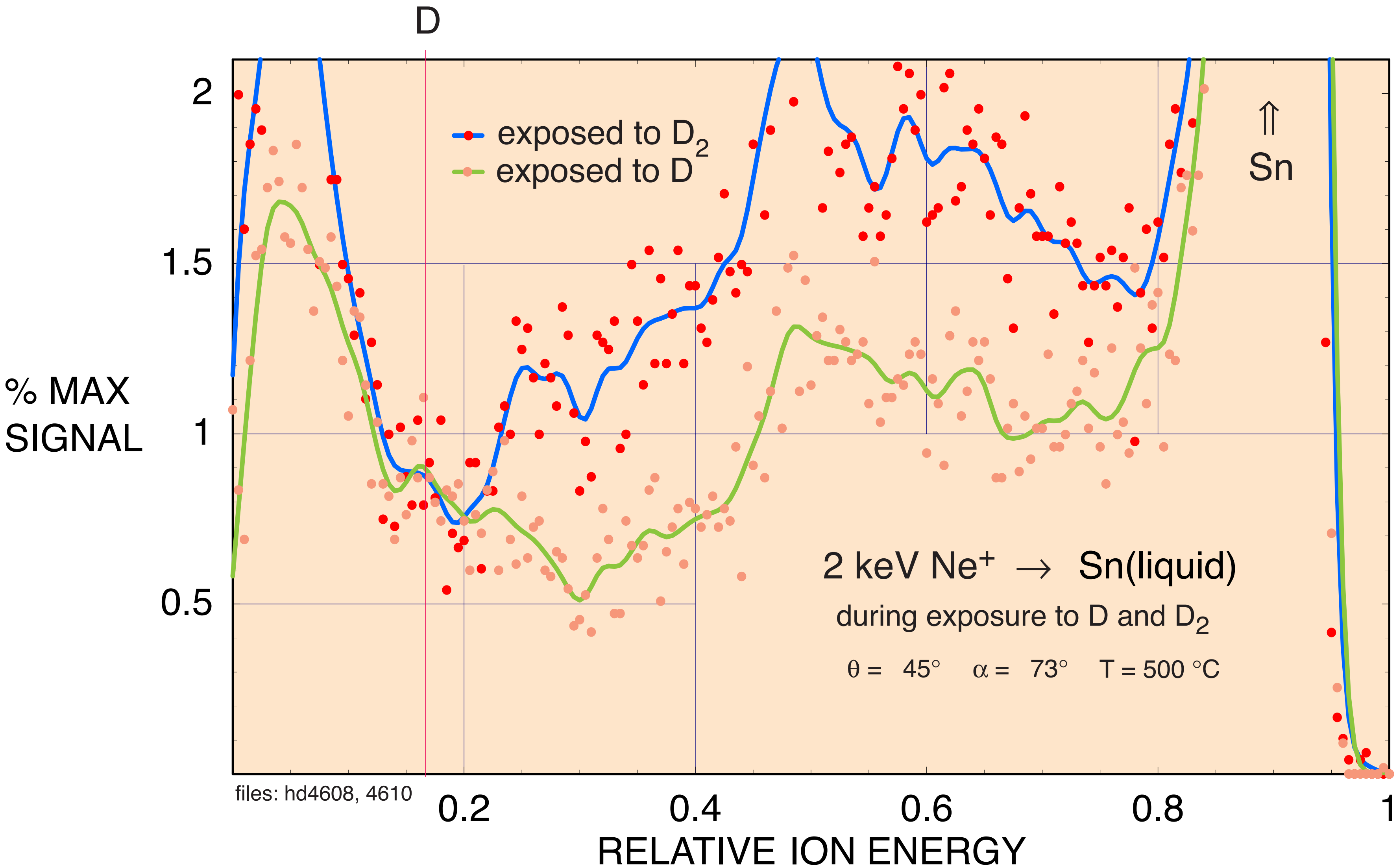
Little effect seen when Sn is exposed to D_2.



At 25 °C, atomic D adsorbs on Sn surfaces.



D is not observed on the surface of liquid Sn.



Summary and plans

- Results are summarized in the following table:

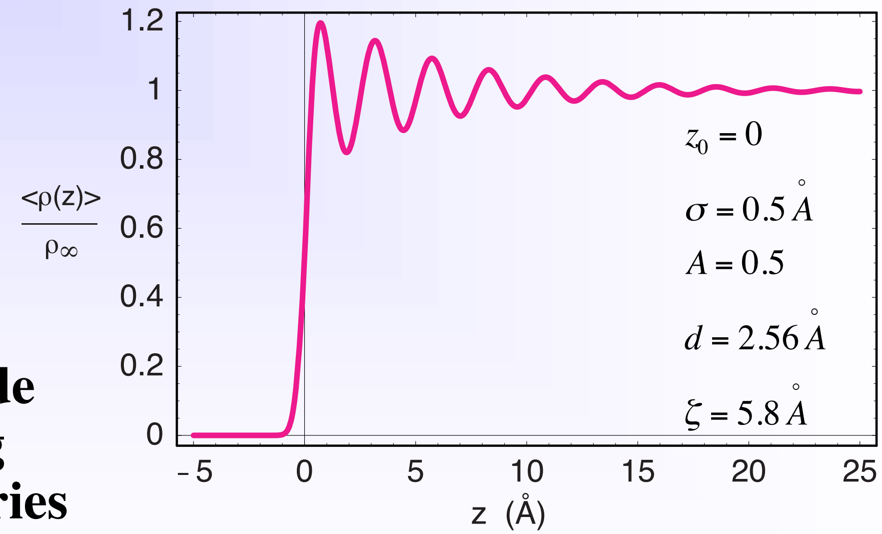
adsorption of D on Sn		
D species	T=25 °C	T=500 °C
atomic	Yes	No
molecular	No	No

- Plans:
  - Quantify data to obtain D surface coverages.
  - Conduct similar experiments for Ga.
  - Measure IID cross sections on Li (and Ga).

Liquid-surface sputtering model development

D. Buchenauer and R. Bastasz *(Sandia National Laboratories)*
W. Eckstein *(Max-Plank-Institut für Plasmaphysik)*

- **The effect of surface density stratification and coordination number need to be introduced into sputtering calculations for liquid metals**
- **Use liquid surface density model from the literature**
  - **Guide to surface values for Li can be made from other materials**
- **Use Monte Carlo TRIM code (TRVMC98) for calculating incident and recoil trajectories and calculating collision cascade**
  - **Stationary surface layering**



$$\frac{\langle \rho(z) \rangle}{\rho(\infty)} = erf\left[\frac{z - z_0}{\sigma}\right] + \theta(z) A \sin\left(\frac{2\pi z}{d}\right) e^{-z/\zeta}$$

Surface atom binding model will strongly influence sputtering

- **Working with Eckstein to extend TRIM to accommodate liquid surface effects**
  - Increasing the number of layers (presently 3)
  - Revising collision bookkeeping to correctly handle density variations in very thin layers
  - Incorporating improved binding energy model
- **Upgraded computing power**
  - Time for 6 x 6 matrix of results reduced to ≈ 1 hour